Experimental Results on Diffraction

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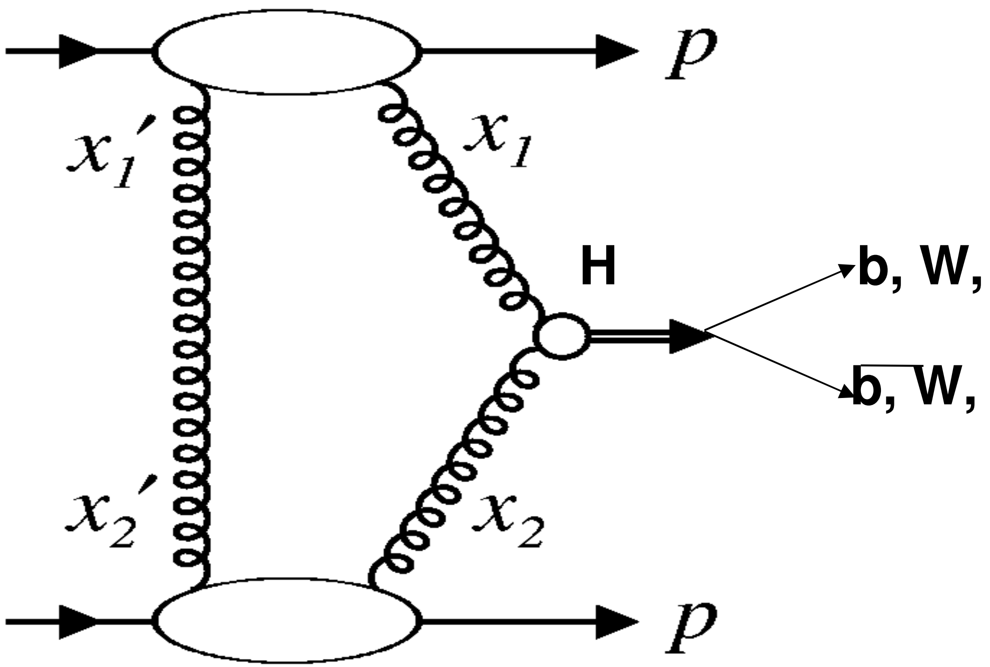
Outline

- **Diffractive processes and kinematics**
- **Measuring diffractive parton density functions**
- **Survival probabilities**
- **Central exclusive production of dijets, diphotons and dileptons**
- **Forward look to the LHC**
- **Summary**

The catalyst:
Central Exclusive Higgs Production



Apologies for not covering everything; no time for vector mesons, γγ collisions, ... !

Diffractive processes and kinematics

Kinematics of pp diffraction

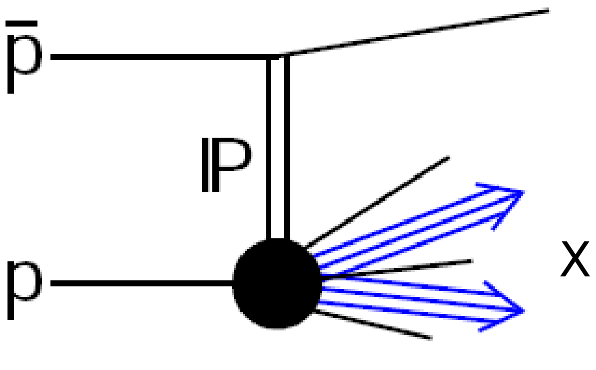
- **Single diffractive dissociation (SDD)**

p p → [p' + IP] + p → p' X

$\xi = 1 - p'_L/p_L$ fractional longitudinal momentum loss of proton

$t = (p - p')^2$ four-momentum transfer squared at proton vertex

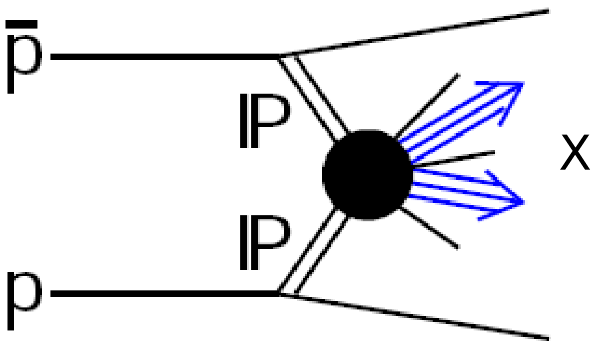
$M_X = X^2$ invariant mass of X



- **Double Pomeron exchange (DPE)**

$p_1\ p_2 \rightarrow [p'_1 + IP] + [p'_2 + IP] \rightarrow p'_1\ X\ p'_2$

$\xi_1, \xi_2, t_1, t_2, M_X$



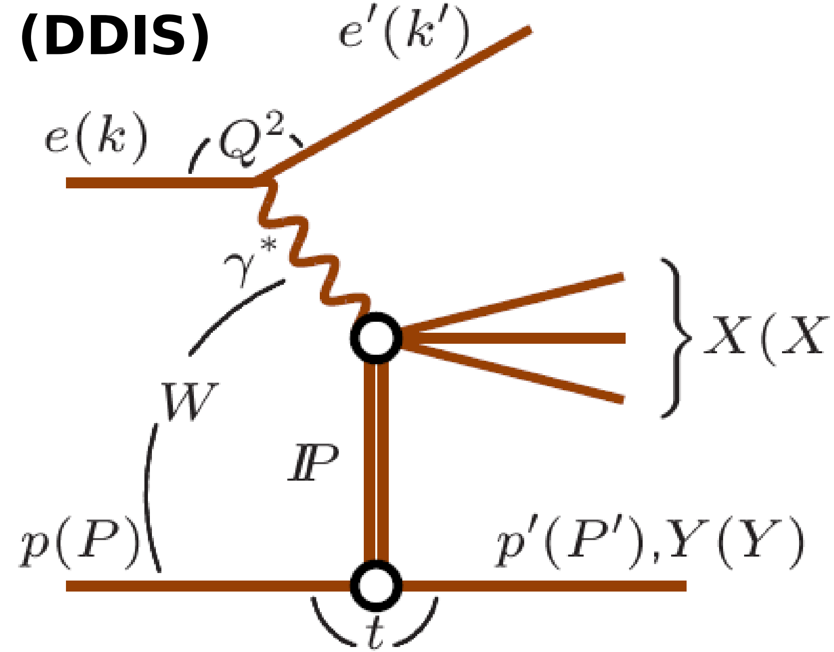
IP = colourless combination of gluons and quarks with vacuum quantum numbers

Kinematics of ep diffraction

Diffractive deep-inelastic scattering (DDIS)

e p → [e + γ*] + [p' + IP] → e X p'

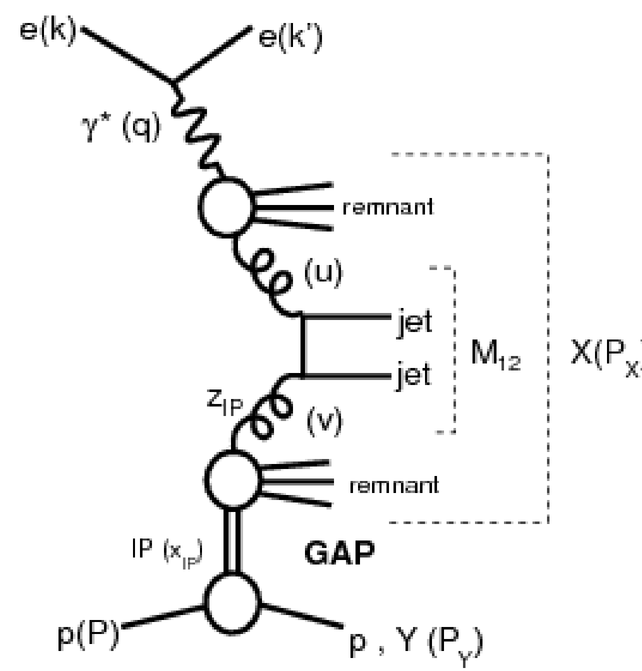
$Q^2 = -q^2 = (k - k')^2$	photon virtuality
$x = Q^2 / 2q.P$	Bjorken-x
$t = (P-P')^2$	four-momentum transfer squared at proton vertex
$M_X = X^2$	invariant mass of X
$x_{IP} = q.(P-P') / q.P$	fractional momentum loss of proton
$\beta = x/x_{IP}$	momentum fraction carried by quark out of pomeron



Diffractive photoproduction (DPHP)

e p → [e + γ] + [p' + IP] → e X p'

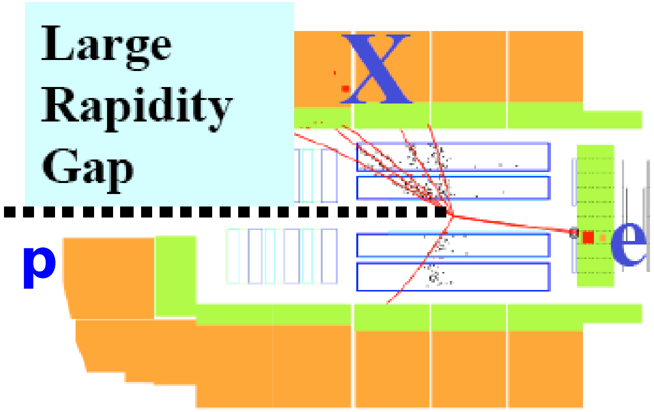
x_γ = P.u / P.q	fractional momentum from photon to hard interaction
z_{IP} = q.v / q.(P-P')	fractional momentum from pomeron to hard interaction



Measuring Diffractive Parton Density Functions at HERA

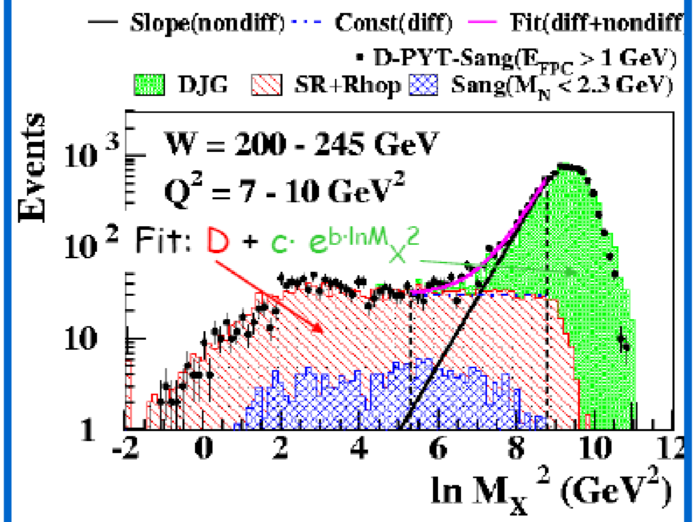
Experimental selection

Large Rapidity Gap selection



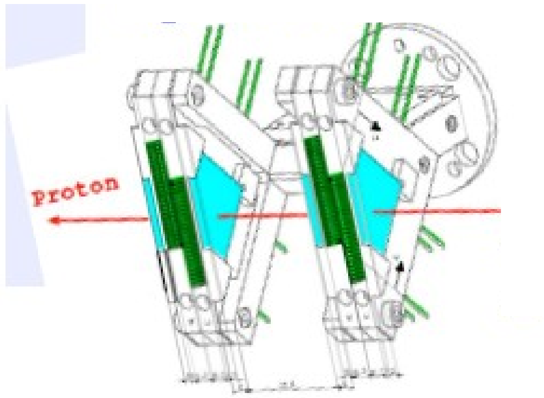
- require large rapidity gap (LRG) spanning at least $3.3 < \eta < 7.5$
- kinematics is measured from X system; integrate over $|t| < 1$ GeV² and $M_Y < 1.6$ GeV

Fit of M_X distribution



- extract diffractive sample from fit of $D + C \exp(b \ln M_X^2)$ to M_X distribution
- kinematics is measured from X; integrate over $|t|$ and $M_Y < 2.3$ GeV

Proton tagging

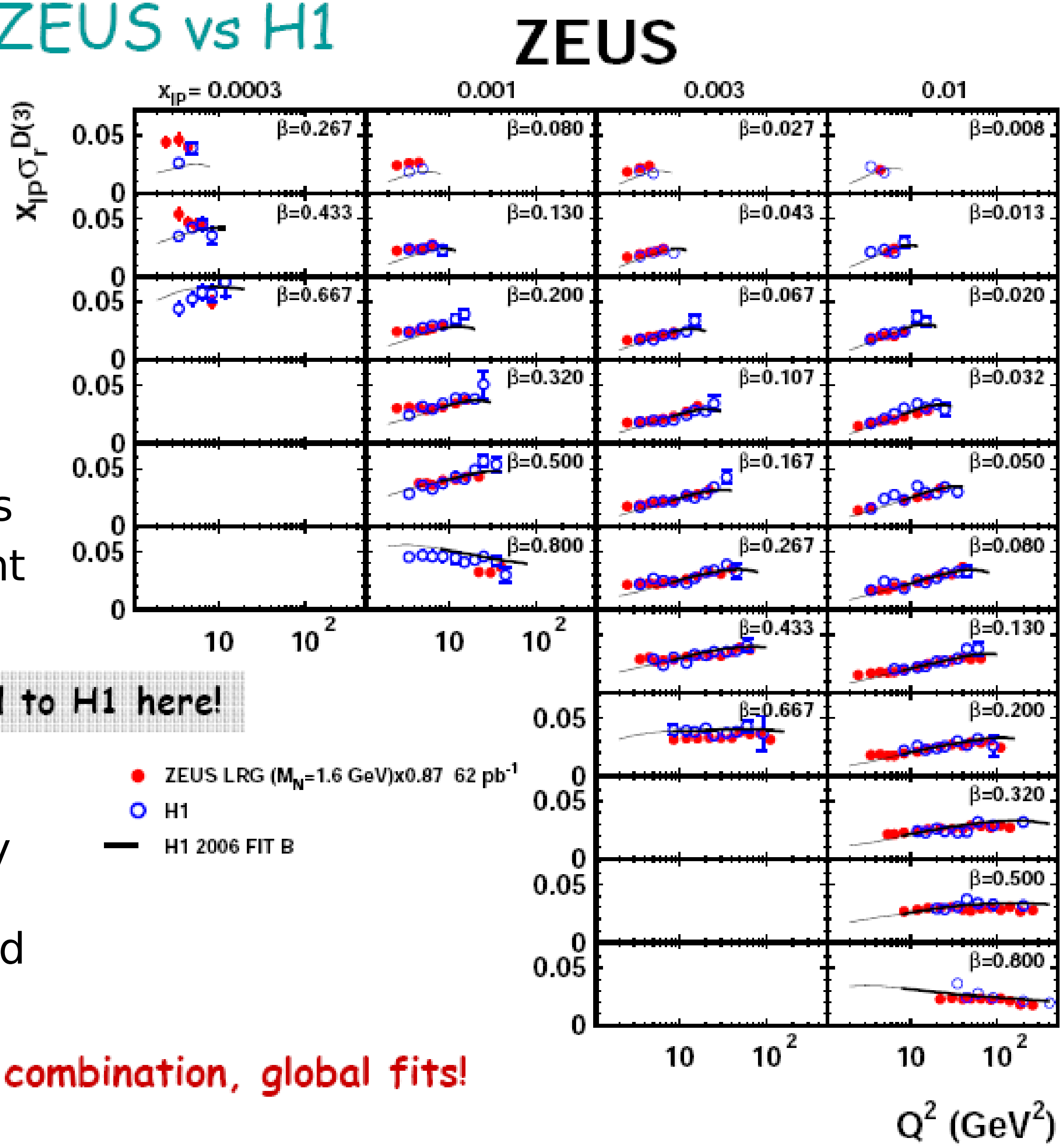


- Detect forward proton → no proton dissociation
- Kinematics from proton momentum → direct measurement of t

Different systematics → non-trivial to compare!

Cross section measurement

$\sigma_r^{D(3)}$ LRG ZEUS vs H1



- LRG, M_X and LPS measurements from H1 and ZEUS all consistent within uncertainties

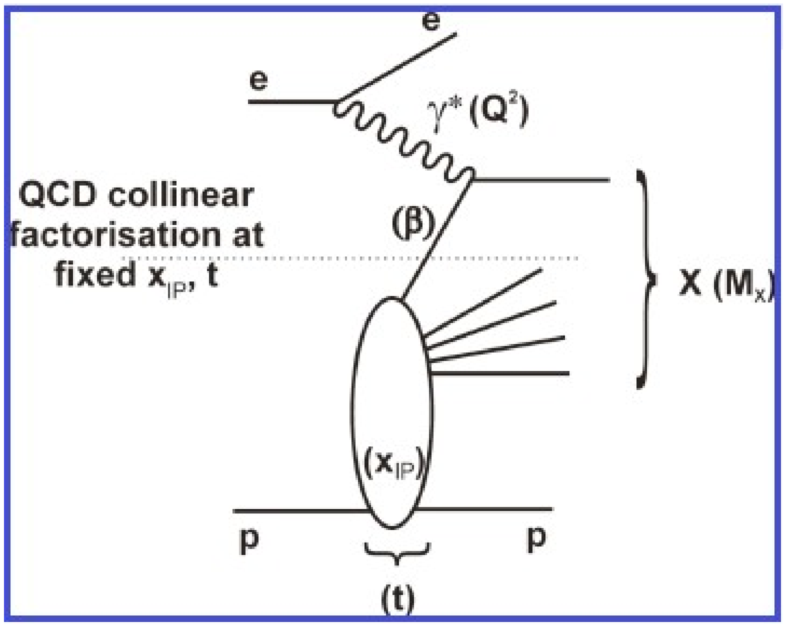
ZEUS normalised to H1 here!

- Remaining normalisation difference of 13% is covered by the uncertainty on the proton dissociation correction (8%) and the relative normalisation uncertainty (7%)

Time for data combination, global fits!

QCD and vertex factorisation

- **QCD hard scattering collinear factorisation (Collins)**

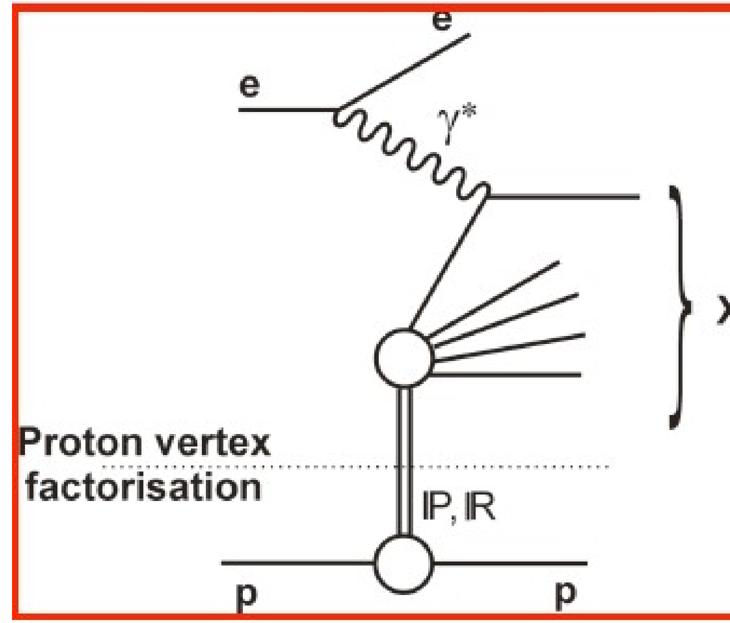


$$d\sigma^{ep\to eXY} = f_i^D(x, Q^2, x_{I\!P}, t) \otimes d\sigma^{ei}(x, Q^2)$$

Diffractive Parton Density Function (DPDF)

➜ exact in DDIS

- **Proton vertex factorisation (Regge)**



$$f_i^D(x, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) \cdot f_i^{I\!P}(\beta = \frac{x}{x_{I\!P}}, Q^2)$$

$$+ n_{I\!R} f_{I\!R/p}(x_{I\!P}, t) \cdot f_i^{I\!R}(\beta = \frac{x}{x_{I\!P}}, Q^2)$$

➜ approximation inspired by Regge theory

From cross sections to DPDFs

H1 2006 DPDF fit

NLO QCD fit of $\alpha_{IP}(0)$, n_{IR} + polynomials for DPDF at Q_0^2 (reggeon flux and pdf is fixed)

- Fit A

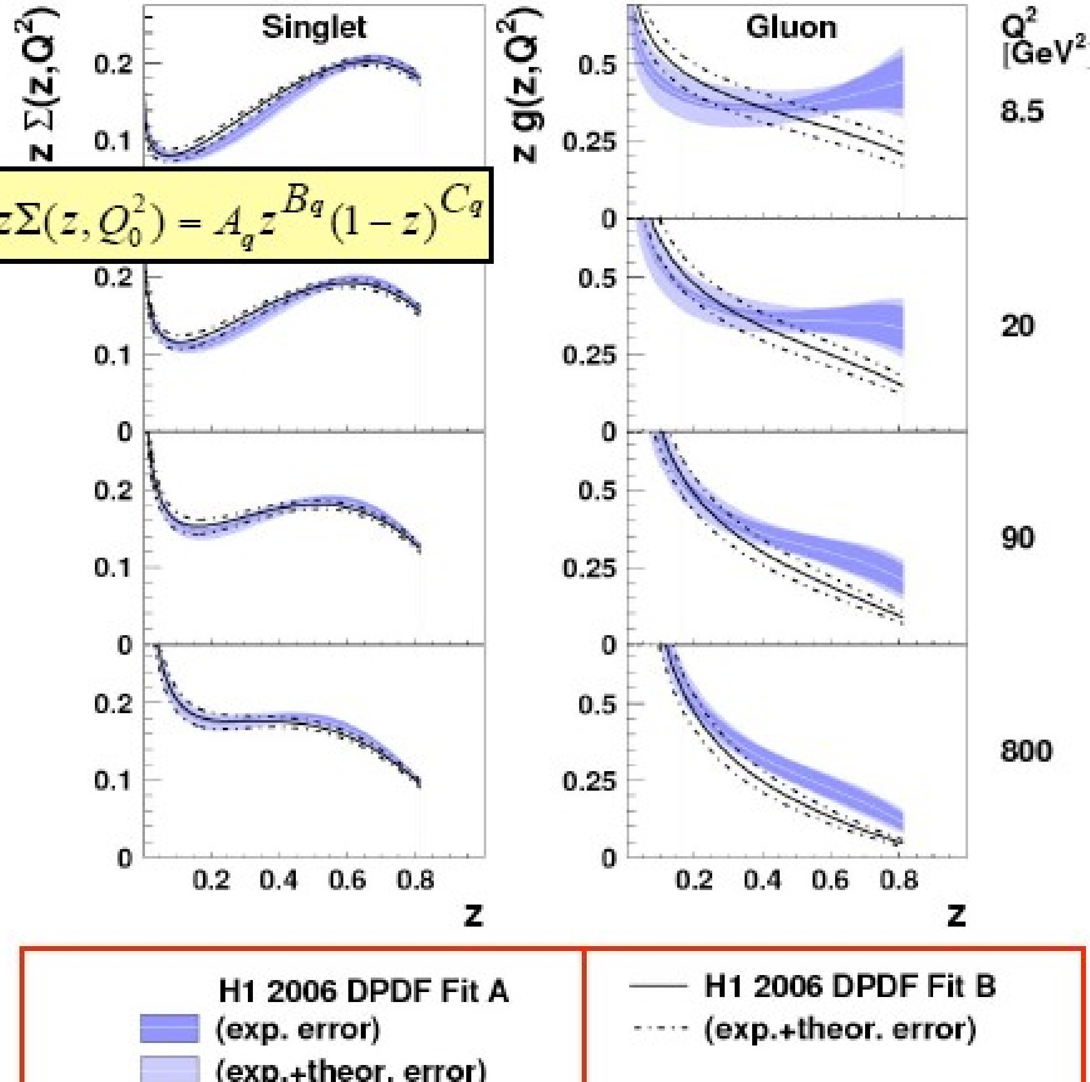
  χ^2 = 158 / 183 d.o.f.

- Fit B

  χ^2 = 164 / 184 d.o.f.

→ Quarks very stable

→ Gluons stable a low z, but no sensitivity at high z

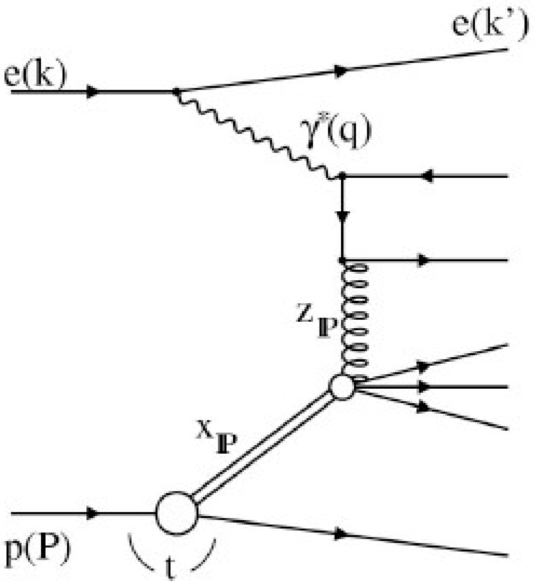


$$z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$$

$$z_g(z,Q_0^2) = A_g(1-z)^{C_g}$$

$$z_g(z,Q_0^2) = A_g$$

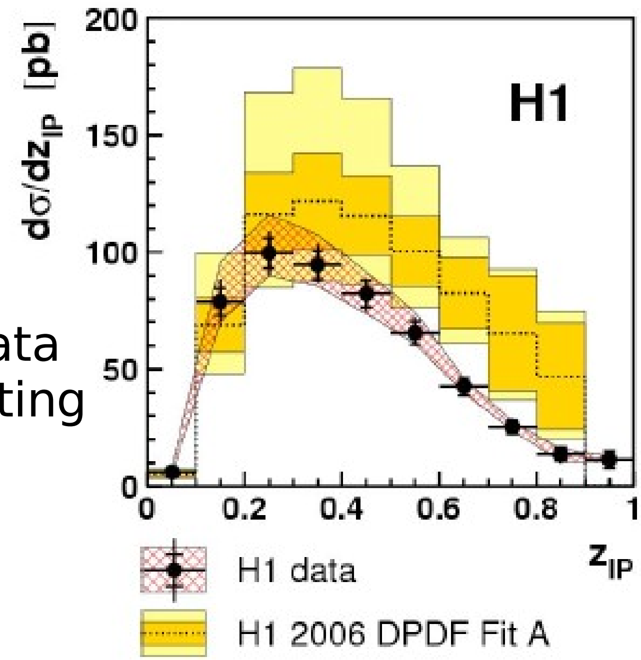
Comparison to DDIS dijets



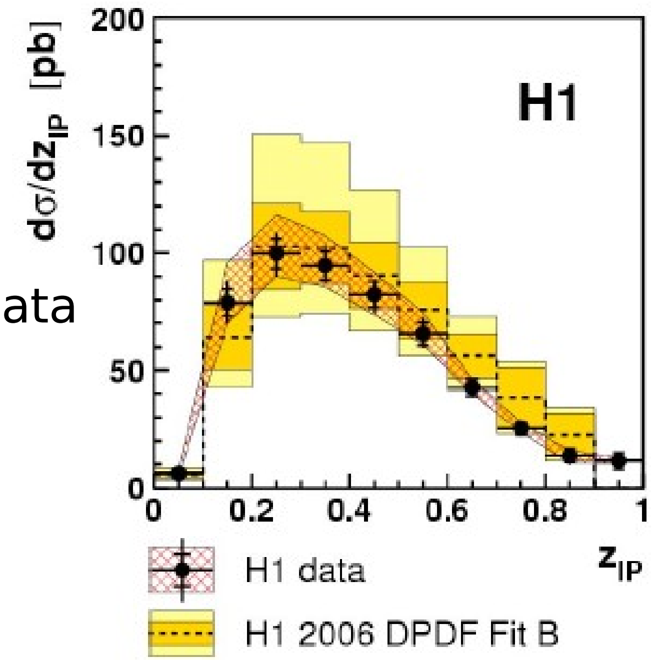
$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$

sensitive to gluon at high z!

Fit A in good agreement with data at low z, overshooting at high z



Fit B in good agreement with data at all z



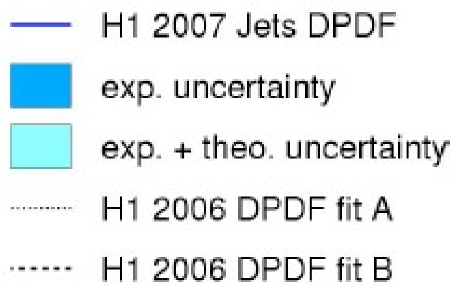
→ QCD factorisation holds in DDIS

→ Fit B preferred by DDIS dijets

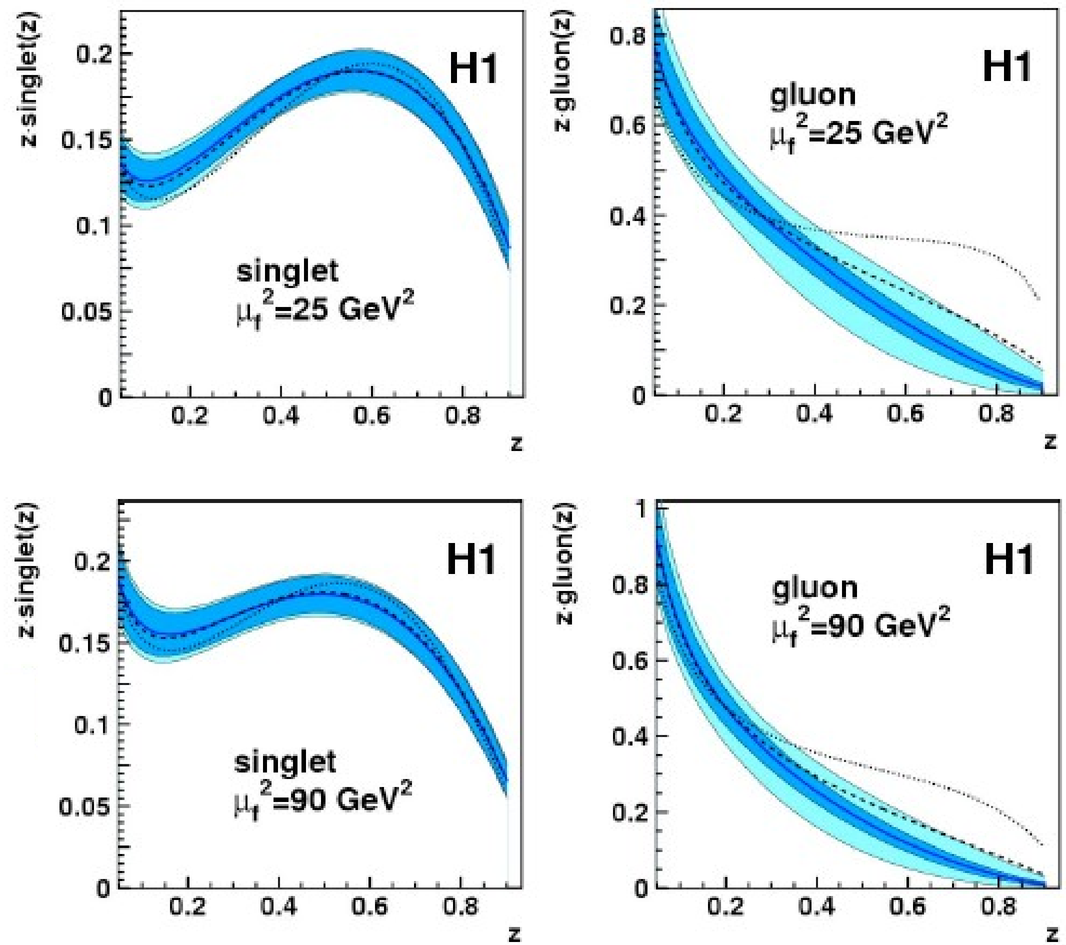
Combined fit

H1 Jets 2007 DPDF fit

use DDIS dijet data as additional constraint in a NLO QCD fit



χ^2 = 196 / 218 d.o.f.



$$z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$$

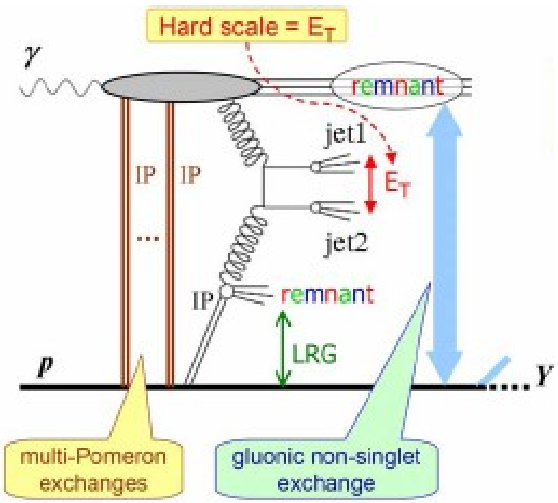
$$z_g(z, Q_0^2) = A_g z^{B_g} (1-z)^{C_g}$$

- → Combined inclusive + dijet fit constrain both quark and gluon DPDFs to similar good precision
- → H1 Jets 2007 fit yields most precise DPDFs to date

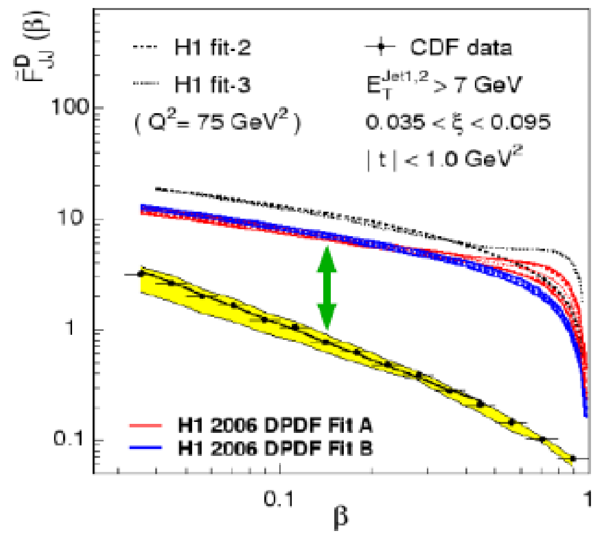
Survival Probabilities

- DPDF fits fail to predict TEVATRON data
  QCD factorisation not expected to hold in pp diffraction!
  - multi-pomeron exchanges
  - remnant interactions
  - Screening

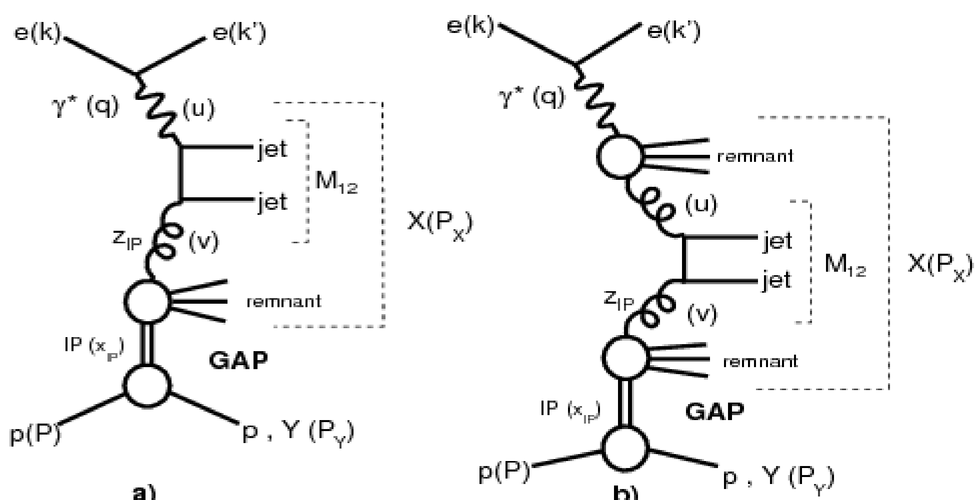
  → gap survival probability



H1 fits vs. Tevatron



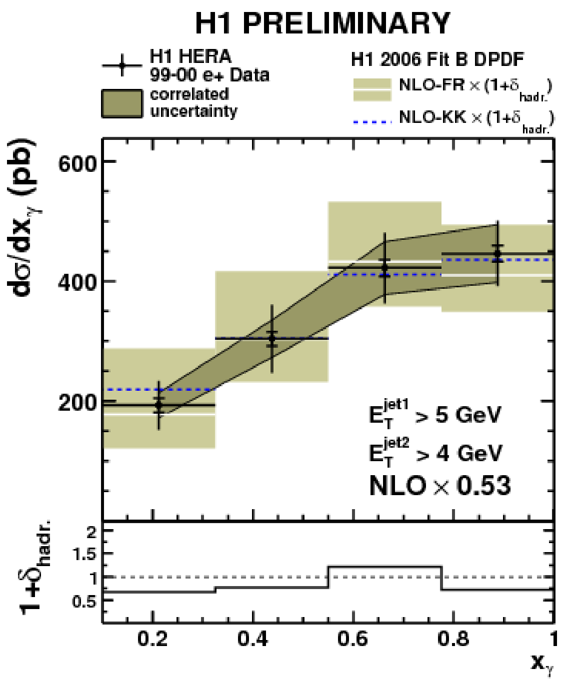
- Look at DPHP dijets

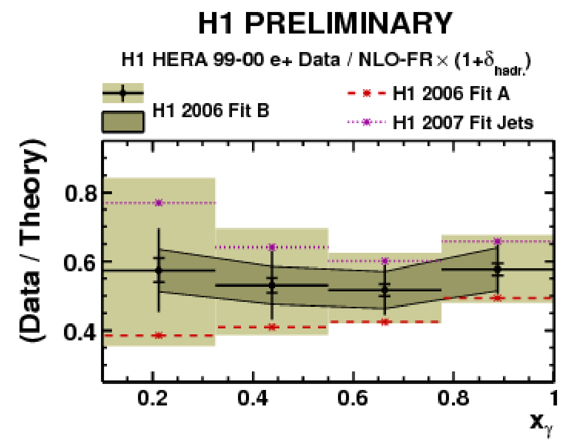


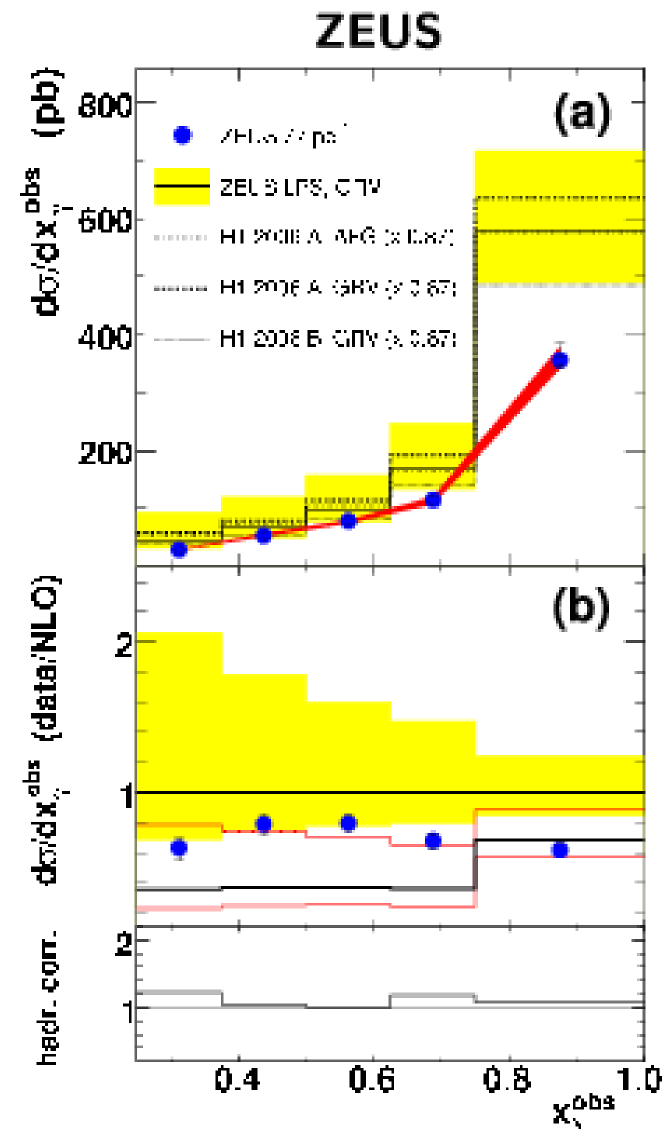
Note: separation between direct and resolved only possible at fixed order!

Direct photon (x_γ = 1) → factorisation should hold	Resolved photon (x_γ < 1) → suppression is expected

Survival probability from H1 and ZEUS







→ Neither experiment observes a x_γ dependence

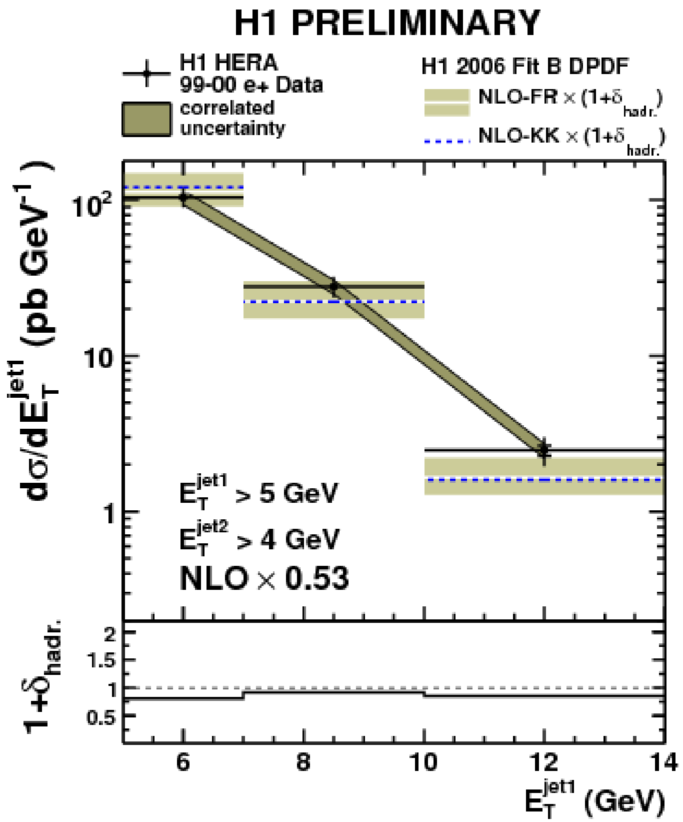
→ H1 observes a larger suppression than ZEUS

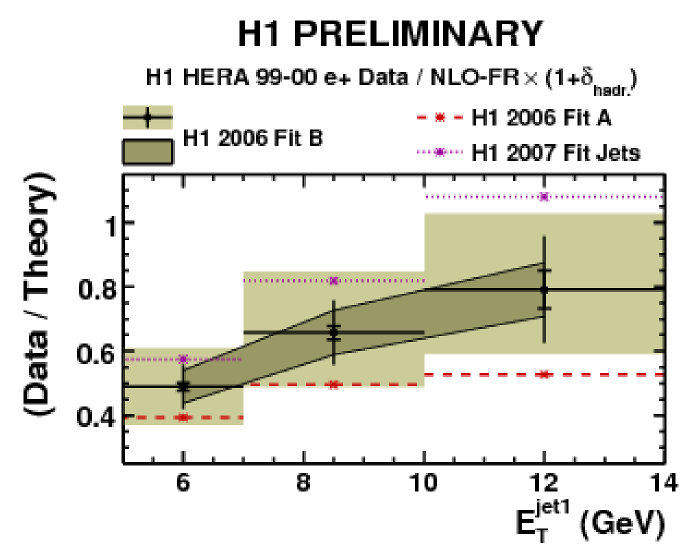
E_T dependence of survival probability

→ No evidence for any difference in survival probability for resolved and direct photons

→ Harder E_T slope in data than in NLO theory

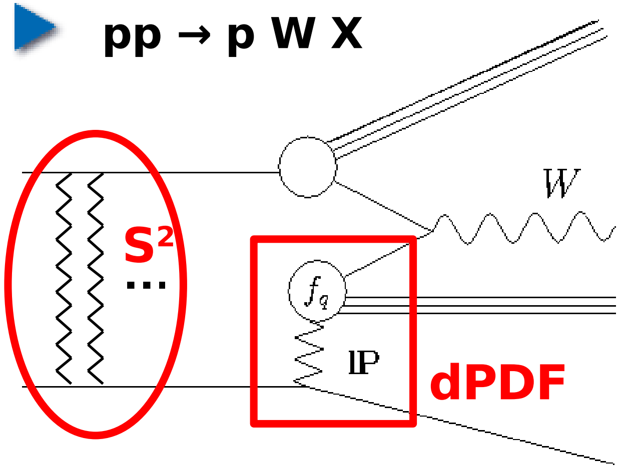
→ H1 and ZEUS suppression factors are consistent





W and Z production at the TEVATRON

- pp → p W X



Motivation:

- Sensitive to quark component of diffractive PDF's
- Probe Rapidity Gap Survival Probability (S^2) – connection to multiple partonic interactions and soft rescattering effects

Selection uses additional fwd detectors of Run-II

(Miniplug calorimeter, Beam Shower Counters, RomanPot proton taggers)

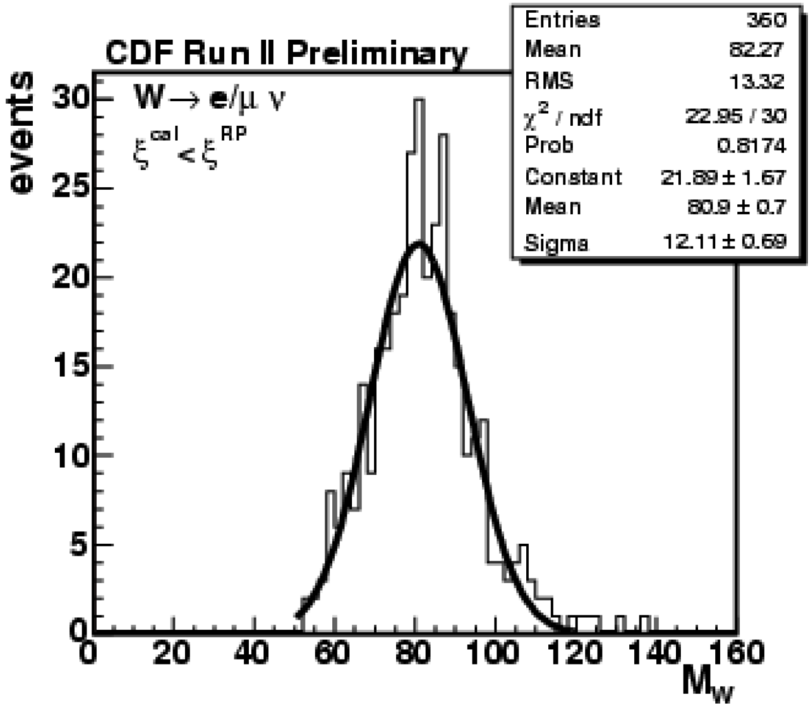
Diffractive W/Z results

R^W (0.03 < ξ < 0.10, |t|<1)= [0.97 ± 0.05(stat) ± 0.11(syst)]%

Run I: R^W =1.15±0.55 % for ξ<0.1→ estimate **0.97±0.47 %** in **0.03 < ξ < 0.10 & |t|<1)**

R^Z (0.03 < x < 0.10, |t|<1)= [0.85 ± 0.20(stat) ± 0.11(syst)]%

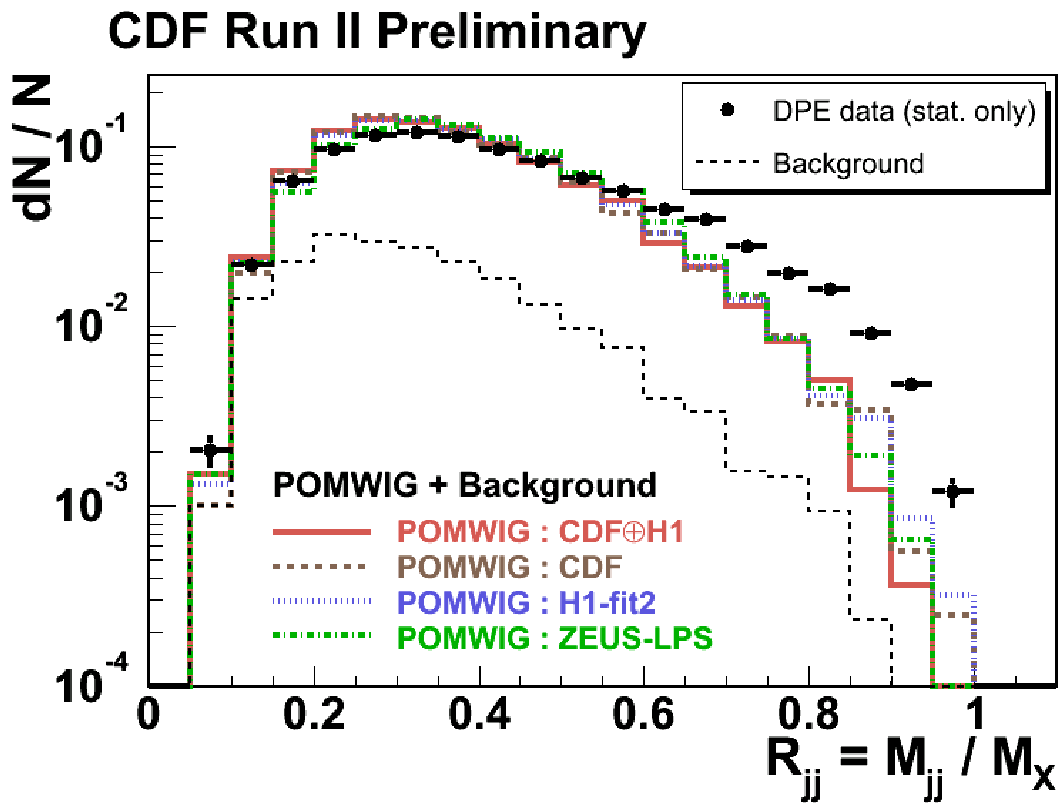
In good agreement with rap gap acceptance corrected Run-I results of D0 and CDF



Central Exclusive Production at the TEVATRON

CEP dijets

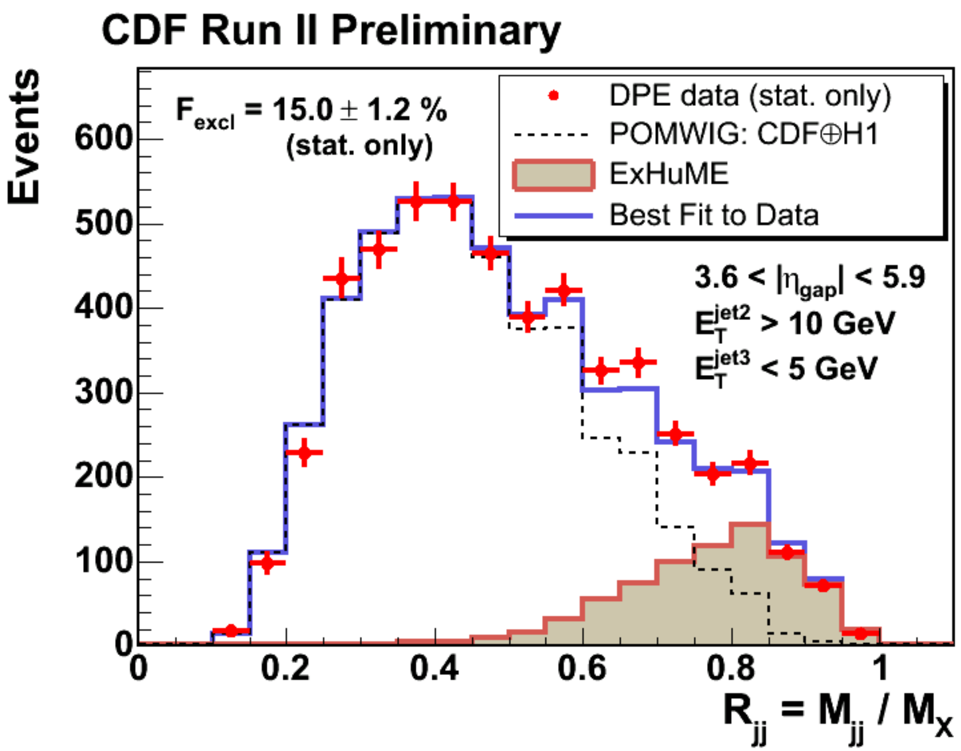
- Strategy: look for excess in dijet mass fraction $R_{jj} = M_{jj}/M_X$
  → expectation for CEP dijets $R_{jj} = 1$

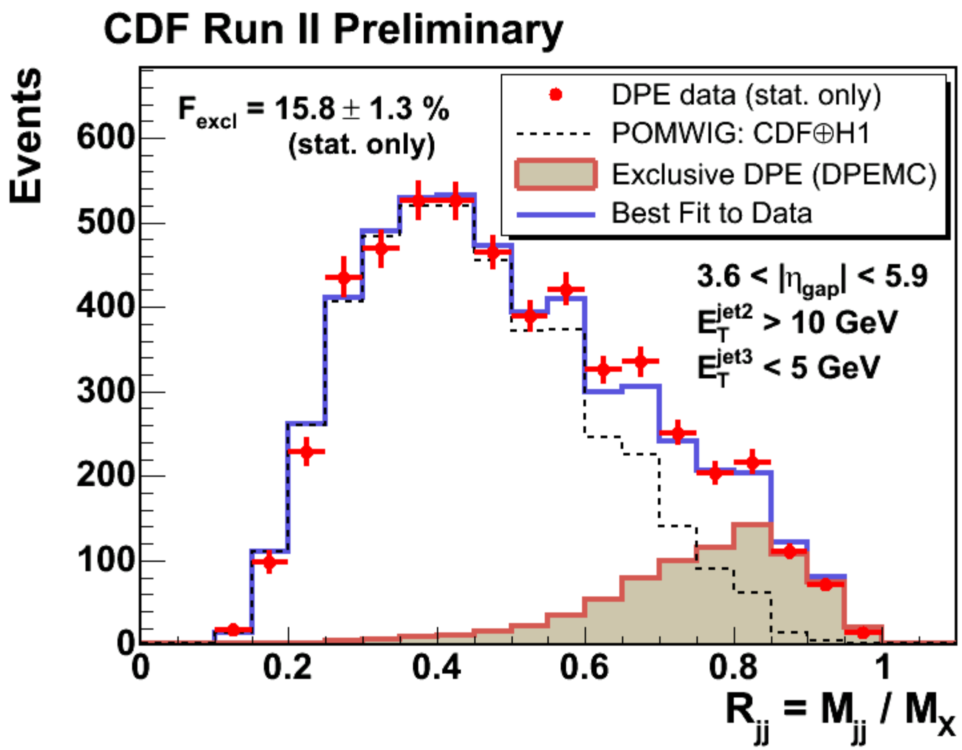


- Excess observed over POMWIG MC prediction at high R_{jj} (POMWIG does not include exclusive production)
- Excess is absent in exclusive b-tagged jets (expected due to $J_z = 0$ selection rule)

Comparison to CEP models

→ Fit R_{jj} distribution by POMWIG+CEP model with free normalisation





- **ExHuME:**

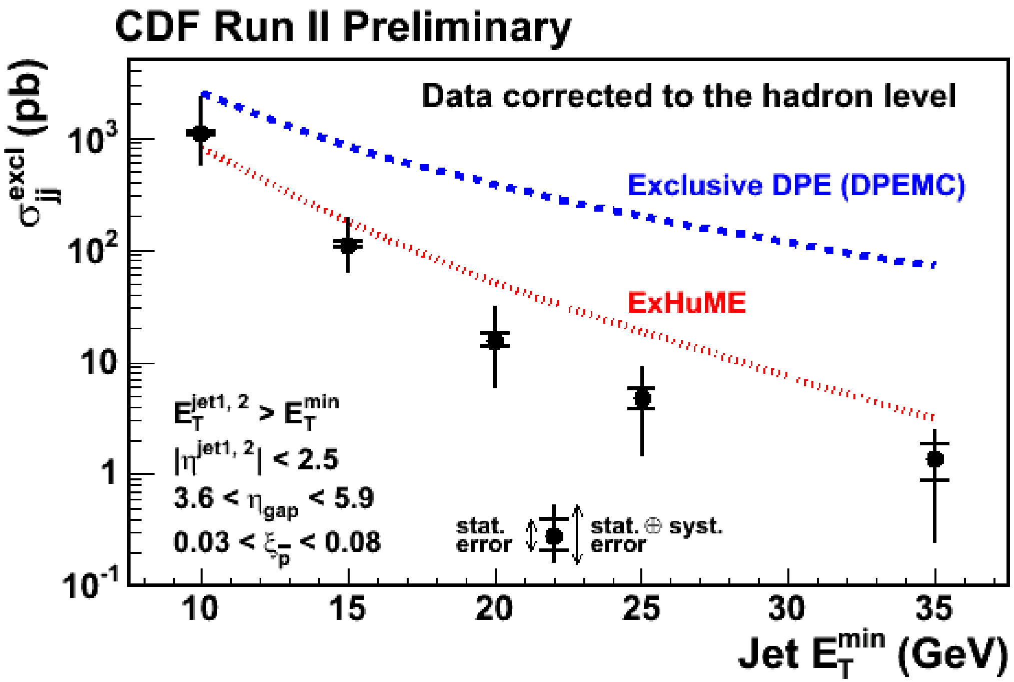
  gg → gg process, based on LO pQCD calculation by Khoze-Martin-Ryskin

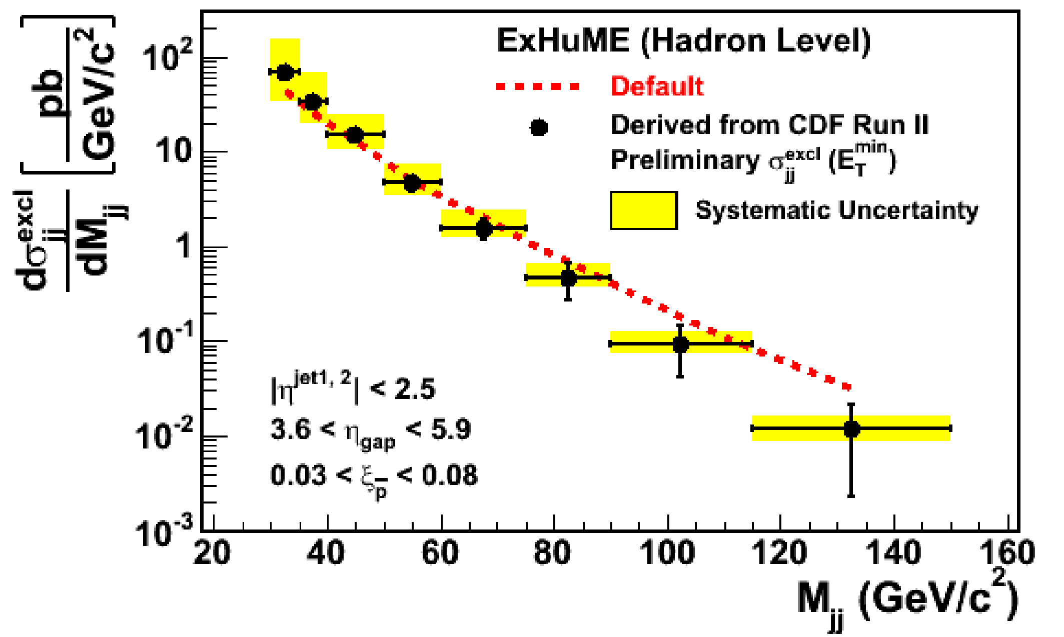
- **DPEMC:**

  exclusive DPE MC based on Regge theory (Bialas-Landshoff model)

→ Both models describe excess of events at high R_{jj} well

Jet E_T and M_{jj} distributions





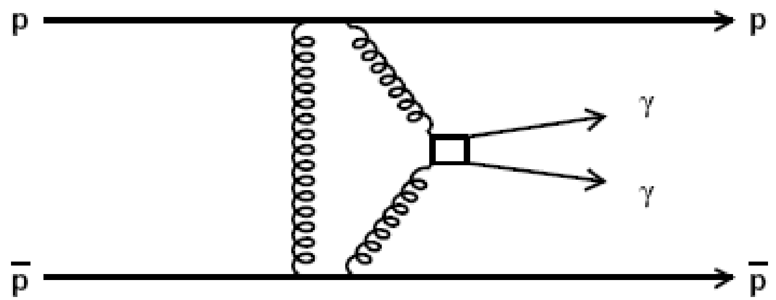
- Data favours ExHuME

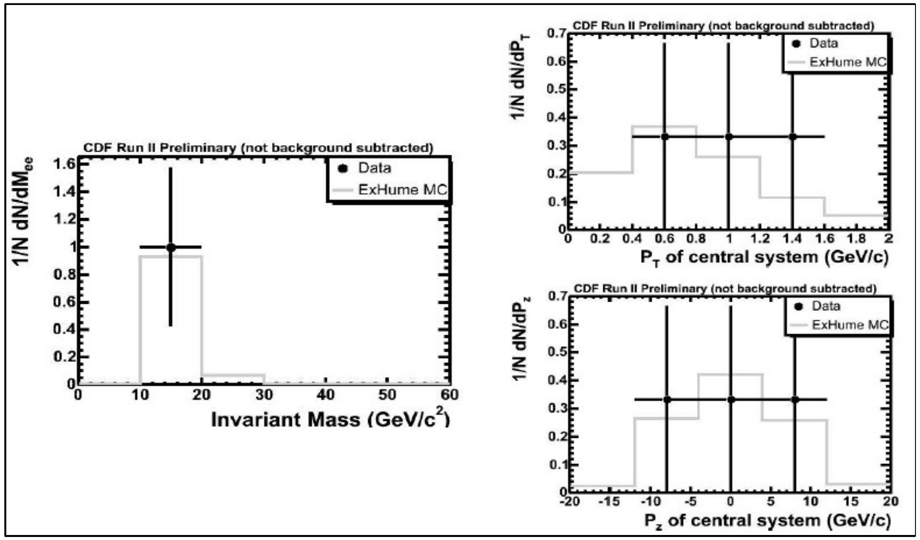
- Good description of M_{jj} distribution by ExHuME (data fall slightly faster)

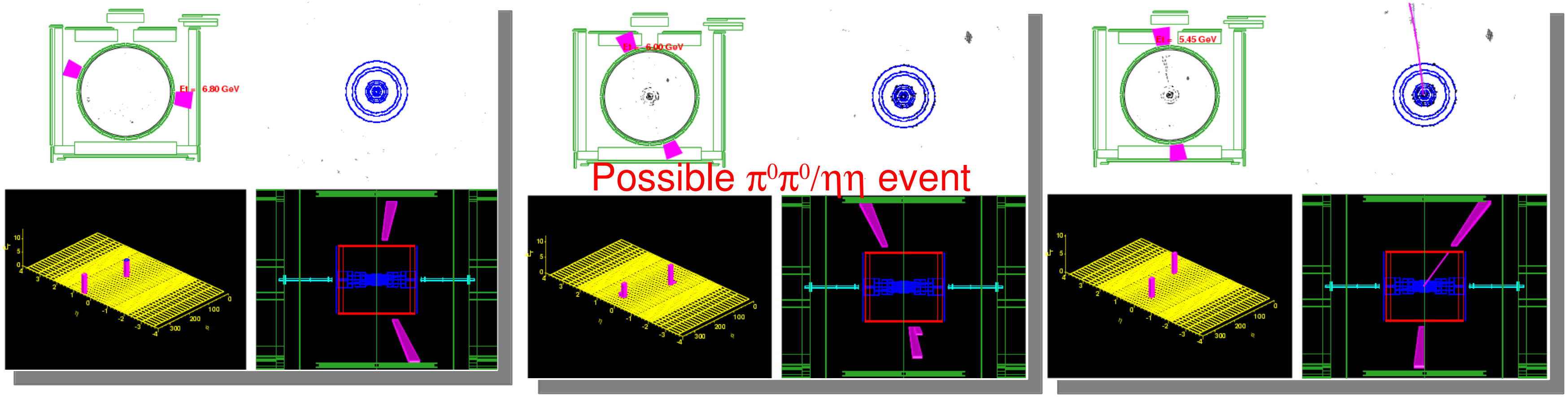
CEP diphotons

pp → pp γγ

- 3 candidate events are found in 532 pb^{-1} of Run II data.
- Background 0.09 ± 0.04 events
- Good agreement on kinematics with ExHuME
- 0.8 $^{+1.6}_{-0.5}$ events predicted from ExHuME - 2 candidates are almost certainly γγ but the $\pi^0\pi^0/\eta\eta$ hypotheses cannot be excluded
- The upper limit of the cross-section pp --> p γγ p is set at 410 fb (95% CL)

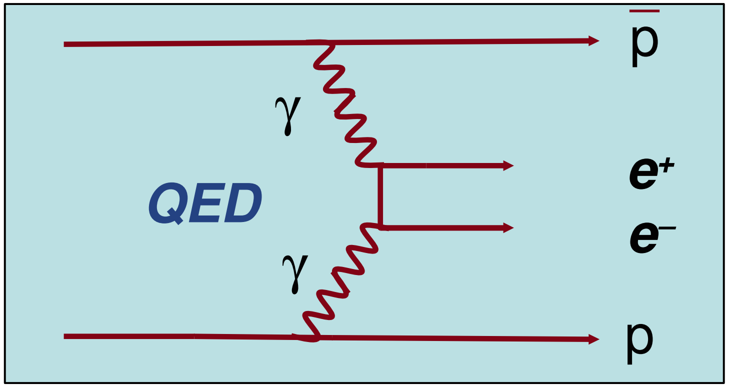


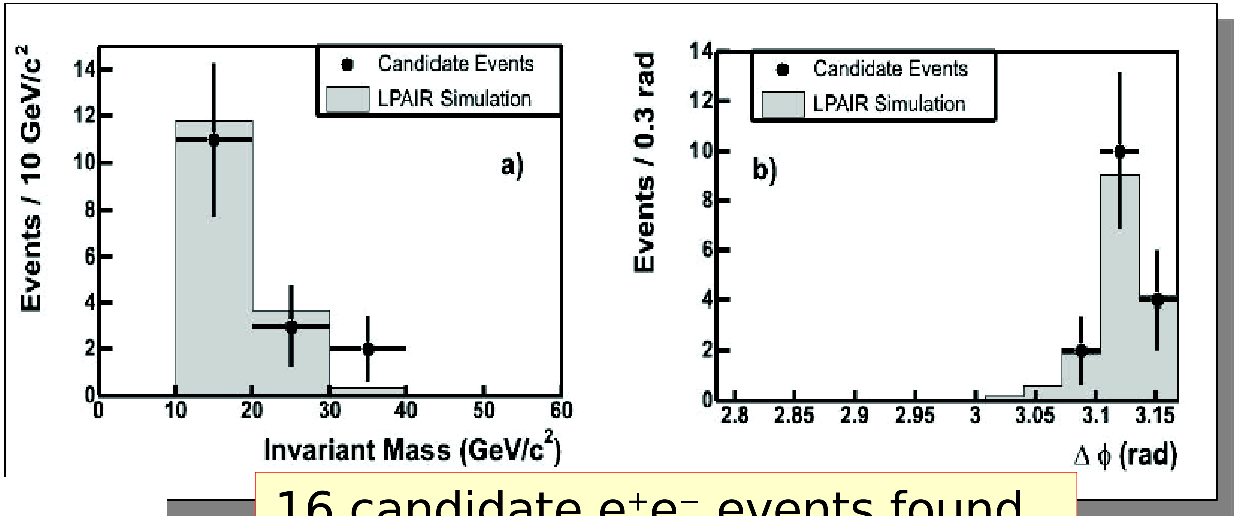




CEP Dileptons

- **pp → pp e⁺e⁻**

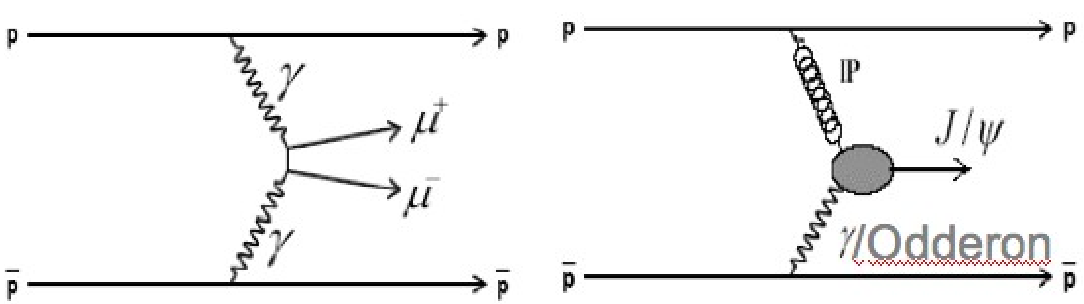


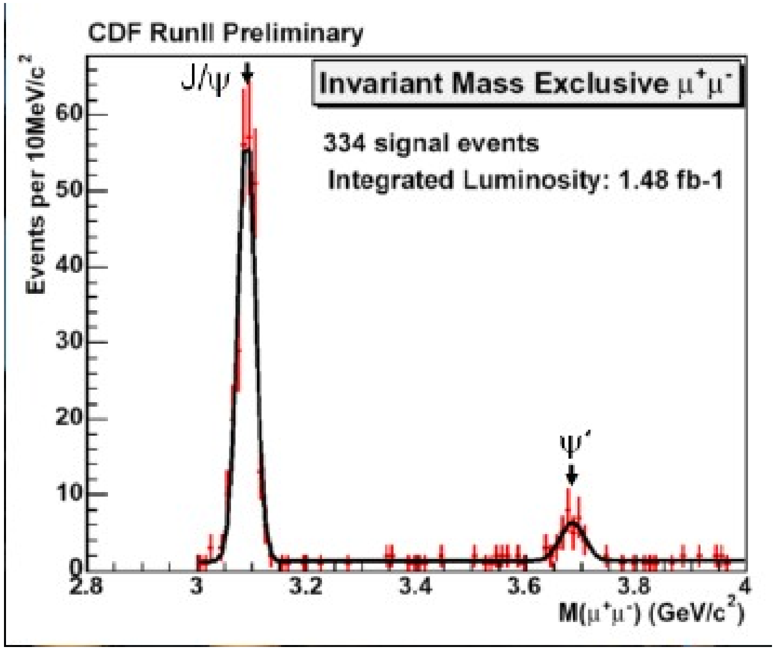


$$\sigma_{MEASURED} = 1.6\ ^{+0.5}_{-0.3}\ (stat) \pm 0.3\ (sys)\ pb$$

16 candidate e⁺e⁻ events found
(expected background 1.9 ± 0.3)

- **pp → pp μ⁺μ⁻**





Forward look to LHC

Diffractive W production

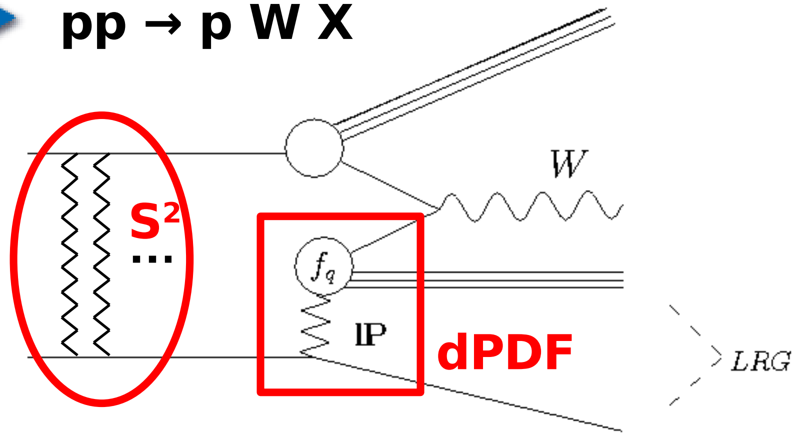
Motivation:

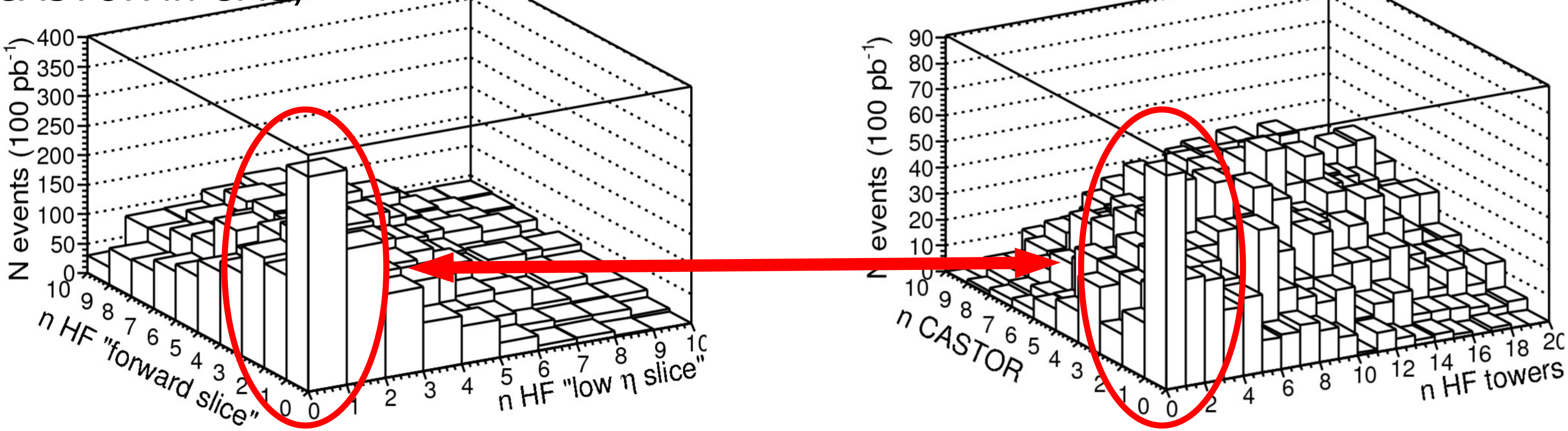
- Sensitive to quark component of diffractive PDF's
- Probe Rapidity Gap Survival Probability (S^2) – connection to multiple partonic interactions and soft rescattering effects

Rapidity gap selection:

- Based on forward activity (e.g. HF, CASTOR in CMS)

pp → p W X

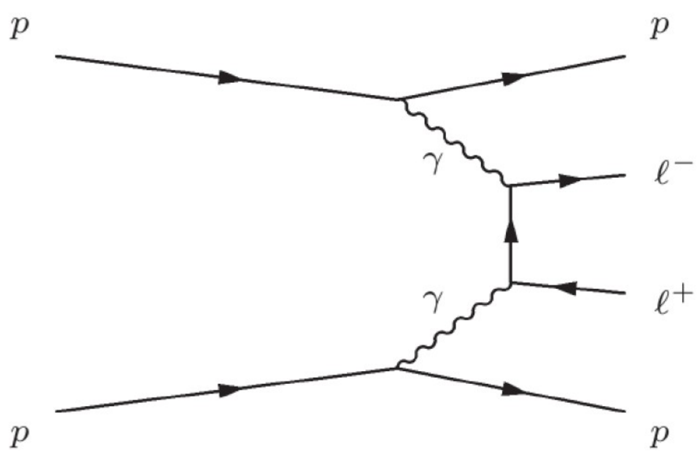




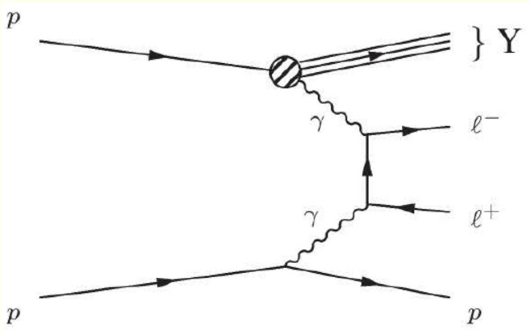
Much better rejection of non-diffractive background with CASTOR (S/B -> 20)
ZDC reduces diffractive dissociation background by 50%

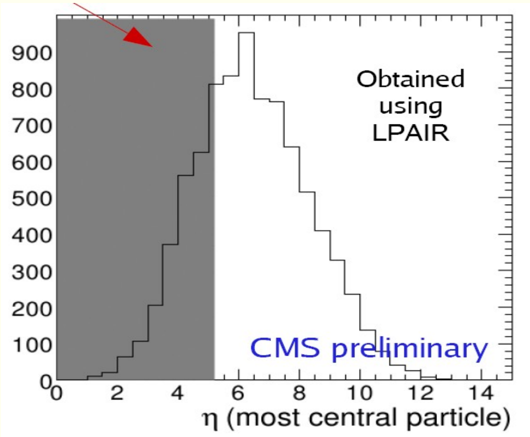
Exclusive dilepton production

- $pp \rightarrow pp\, l^+l^-$



Inelastic background

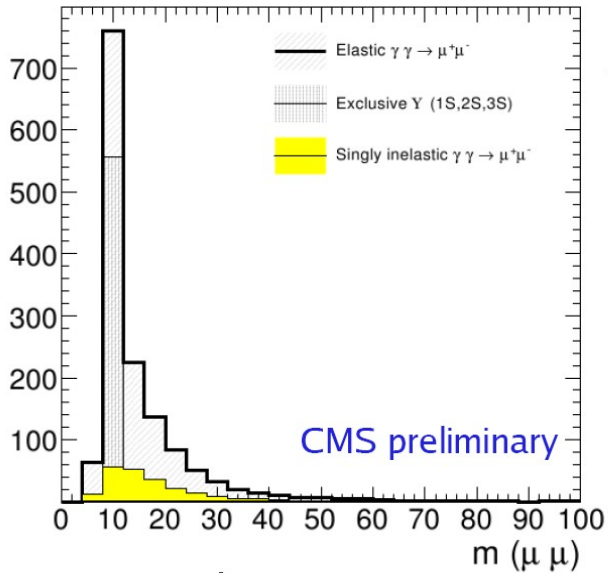


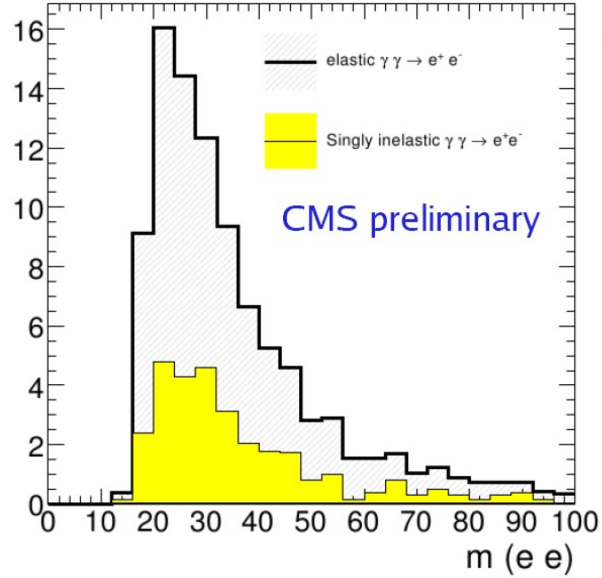


→ can be reduced using CASTOR/ZDC

Motivations:

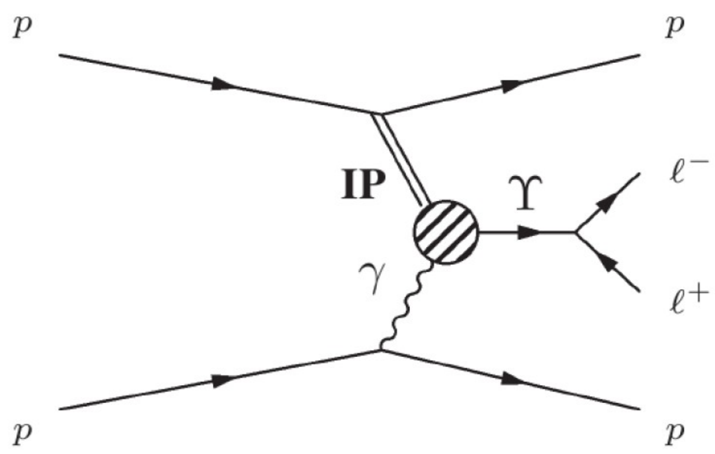
- Nearly pure QED process → luminosity monitoring (precision of 4% is feasible)
- Study of lepton identification
- Calibration of forward proton detectors

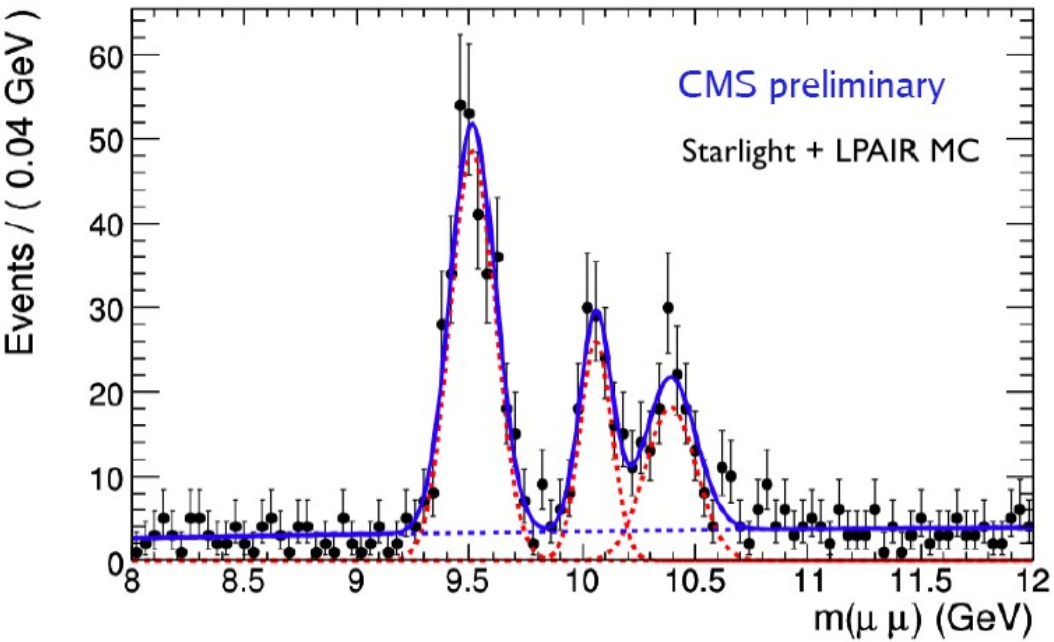




ϒ photoproduction

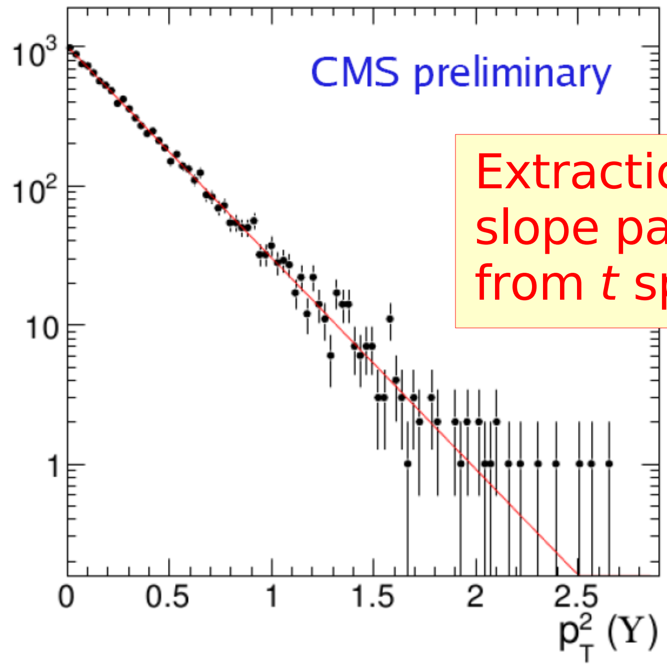
- **pp → ppϒ, ϒ → l⁺l⁻**





Motivations:

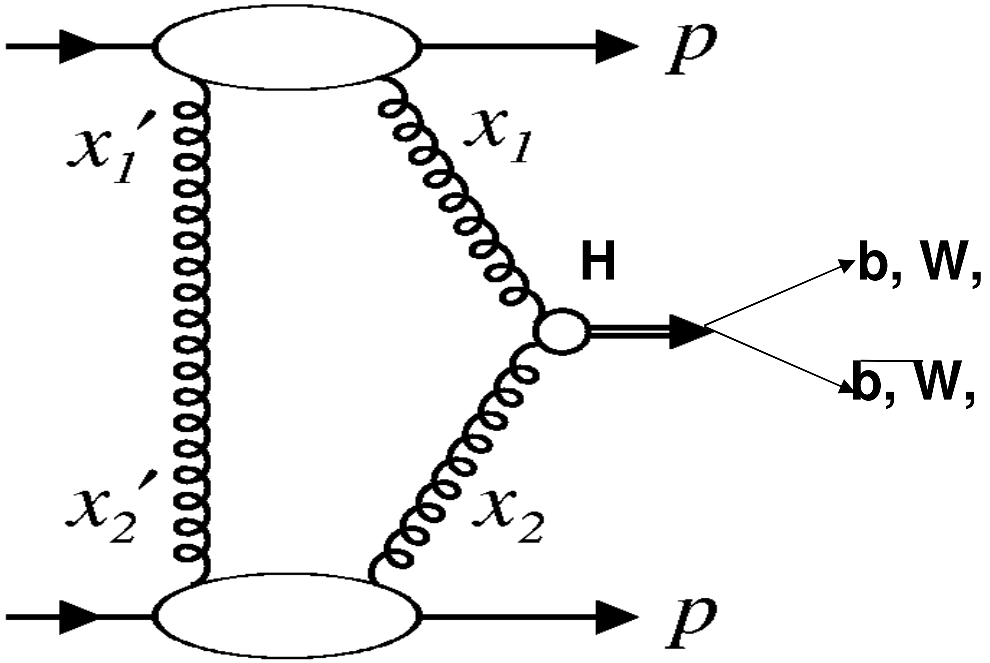
- Measure gluon distribution in proton at low x
- Constrain diffractive/QCD models
- Alignment of forward proton detectors



Extraction of slope parameter *b* from *t* spectrum

CEP Higgs

- Advantages of CEP Higgs channel
  - QCD b$\underline{b}$ background suppressed due to $J_z = 0$ selection rule
  - Determination of m_H through outgoing proton momentum measurement
  - Azimuthal angular correlations yield spin-parity of Higgs
- CEP of dijets, diphotons, χ_c can serve as standard candles to calibrate models
- KMR (supported by CDF CEP dijet measurement) predicts σ(p p → p H p) = 3 fb for a SM Higgs at the LHC
- Discovery possibilities for MSSM, NMSSM Higgs scenarios...



Summary

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- HERA measurements of inclusive DDIS give consistent results for all methods and experiments
- DPDFs are extracted; H1 Jets 2007 DPDF most precise
- No suppression observed in DPHP dijets for resolved photons; survival factor does seem to increase for higher E_T jets
- CEP dijet production is observed at the TEVATRON and can serve as "standard candle" process for CEP Higgs
- KMR model for CEP has been validated by data
- Plans to establish diffractive signals are being developed at the LHC
- CEP Higgs production has some advantage over inclusive channels and discovery potential in some MSSM and NMSSM Higgs scenarios

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